Information and Communication Requirements for Intelligent Control

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Abstract

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As pointed out in [2], the past four decades have witnessed great advances in active control technologies based on deep fundamental results in the theories of estimation, adaptation, stability, and optimality. But just as many subdomains within the field have become mature, new technologies have appeared which promise to raise an exciting new array of challenges. Specifically, recent advances in sensor and actuator technologies, communications technologies, and especially in computer technologies have led to a re-examination of traditional approaches to the design and analysis of active control systems. While basic principles of control and systems engineering provide a firm foundation on which to integrate many of these new technologies, there are also important new areas in which many technical questions remain open.

A large body of recent research has been aimed at the control of systems with large numbers of component sensors and actuators, distributed over some spatial domain and operating asynchronously. Intelligent Vehicle Highway Systems and Air Traffic Management Systems [3] are examples of new technologies which have helped define the central issues in the theory of coordinated control of such systems. The research to be presented here has been aimed at developing a broad theory of what might be called *network-mediated control* systems, within which applications to a wide range of technologies may be understood in a unified way. The emphasis will be on general communications and information processing problems. While I shall mainly discuss general aspects of the theory, I shall also spend some time discussing applications which are being developed with colleagues at Boston University. These include an integrated array of silicon-based MEMS piston actuators ($\sim 200\mu$m) used to control deformable mirrors and an array of small-scale (1 mm) vortex generator jets used to control boundary flow separation over aircraft lifting surfaces. In both cases, implementations entail the solution of two significant conceptual problems. First, there will be constraints on the information carrying capacity in the feedback links connecting the sensors, controller, and actuators. These constraints arise from the design objective of creating very large scale arrays of very small and densely packed devices. More specifically:

1. The most recent designs of MEMS arrays have aimed at packing tens of thousands rather than hundreds of actuators onto each chip. In such designs, it is generally not practical to incorporate direct connections between each micro-device on the chip and control processors and power sources. Such connections must therefore involve multiply shared communication links, and this constrains the communication channel bandwidth available to each device.
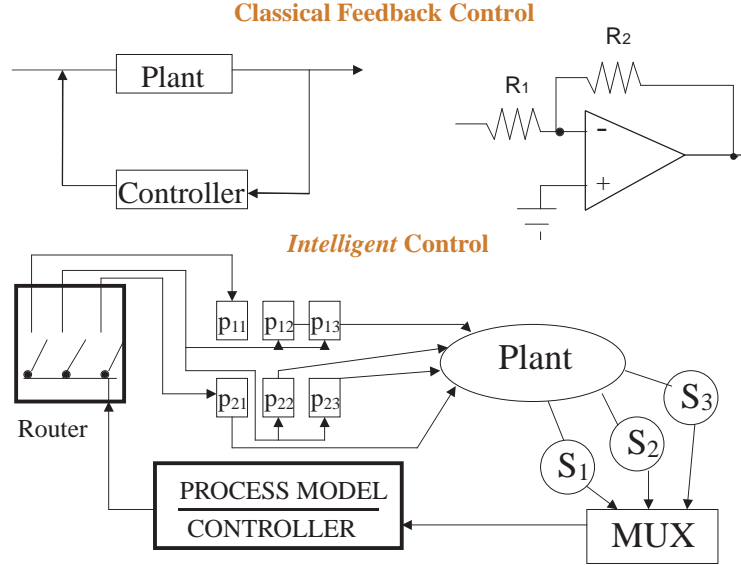
Figure 1: Intelligent control may be distinguished from classical control by a number of features including switched data routing between sensors, controllers, and actuators. moreover, as the theory is being driven by ever more demanding applications, the physics of the plant and its interactions with the sensors and actuators create new challenges in real-time information handling.

2. For the very small scale component devices in these arrays, it is difficult to achieve local closure of feedback loops. Moreover, because any state measurements will be subject to considerable noise, precise state information will be both difficult and costly to obtain.

3. As individual device components are decreased in size, the physical time constants which characterize their operation become very short, which leads to a need for increased channel capacity in feedback links. This requirement is in conflict with item one above.

In this talk, I shall discuss recent results on data rate requirements for implementing stable feedback control [1]. These requirements will be described explicitly for some actual controlled mechanical systems. The second major conceptual problem in the applications cited above involves understanding the physics of sensor and actuator interactions with complex physical processes. This will be discussed in the context of the problem of controlling boundary flows.

References

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